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Influence of Cooling Rate and Copper Content on the Microstructure of Zn-27%Al Alloy under End-chill Casting

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1- Introduction

Zinc-based alloys have been widely used as tribological components for various machines because of their lower density, lower energy requirement for shaping and superior wear properties. However, the mechanical properties of the binary Zn-Al alloys are not suitable for most engineering applications. Studies show that the addition of alloying elements such as Si, Ni, Mg and Cu leads to improved mechanical properties. Addition of 1-3% Cu to the eutectoid Zn-Al alloys improves their mechanical properties, creep resistance and corrosion behavior. Microstructural feature is another effective factor which affects mechanical properties. Cooling rate is proved to be the most effective parameter for controlling the microstructure of the as-cast alloys. It is known that with increasing cooling rate, dendrite arm spacing (DAS) decreases and as a result leads to better mechanical properties. Furthermore, changing the cooling rate may change the percentage of porosity, as well as both the types and the amounts of phases present. Various investigations have been performed by using a number of casting techniques to induce a wide range of microstructural features; however, in most of the studies only one of the parameters (cooling rate, alloying elements, etc.), which can affect the properties of an alloy was considered. Therefore, the aim of this work is to study the effects of cooling rate and Cu content on the microstructure. The influence of cooling rate on size, morphology and percentage of Cu-rich phase is also evaluated.

2- Experimental procedure

In the present work, Zn-27%Al alloys containing different copper content were produced from pure zinc (99.99 wt%), pure commercial aluminum (99.9 wt%) and an Al-Cu master alloy. The alloys were melted in a resistance furnace and degassed with zinc chloride and poured into the end-chill sand mold in the form of cylindrical castings. The schematic illustration of the end-chill apparatus used in this work is shown in Fig.1. The chemical compositions of the produced alloys determined by atomic absorption spectroscopy are listed in Table 1.

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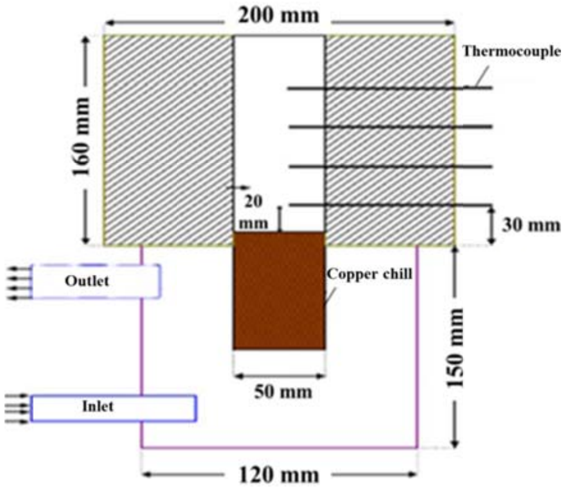

Figure1 Schematic illustration of the end-chill apparatus used in this work

Table 1 Chemical compositions of produced alloys

Alloys	Elements (wt%)				
	Zn	Mg	Fe	Cu	Al
Zn-27Al	Bal.	0.01	0.1	-	25.5
Zn–27Al-1Cu	Bal.	0.02	0.1	1.1	26.2
Zn–27Al-2Cu	Bal.	0.01	0.1	2.2	26.9
Zn–27Al-4Cu	Bal.	0.01	0.1	4.2	27.6

To study the microstructural features, selected surfaces were polished and etched. Etching solution was composed of 5g CrO_3 and 0.5g Na_2SO_4 in 100ml H_2O. The microstructure was examined by optical microscope and scanning electron microscope equipped with energy dispersive spectroscopy. The phase identification was also conducted by means of X-ray diffraction analysis. Phase percentage and dendrite arm spacing (DAS) was calculated by Aquinto Image Analyzer.

3- Results and discussion

Fig. 2 shows the microstructure of Zn-27Al-2Cu alloy at different positions from the chill.

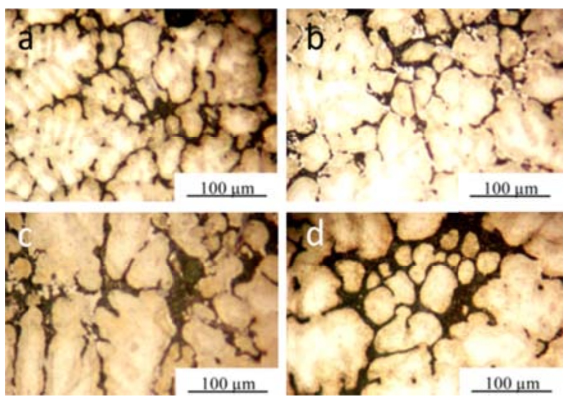

Figure 2 Microstructure of Zn-27Al-2Cu alloy at: (a) 20; (b) 50; (c) 90; (d) 110 mm from the chill

It can clearly be seen from the images that the cast has solidified in an equiaxed grain structure at all positions with respect to the chill. It is reported that the equiaxed structure prevails in Zn-27%Al cast at cooling rates less than 1K/s. Moreover, as cooling rate decreases, with an increase in the distance from the chill, the porosity, DAS and interdendritic phase percentage of the alloy increased.

Fig. 3 indicates the mean values of dendrite arm spacing as a function of distance from the chill. The primary and secondary DAS has decreased with increasing distance from the chill and decreasing cooling rate,.

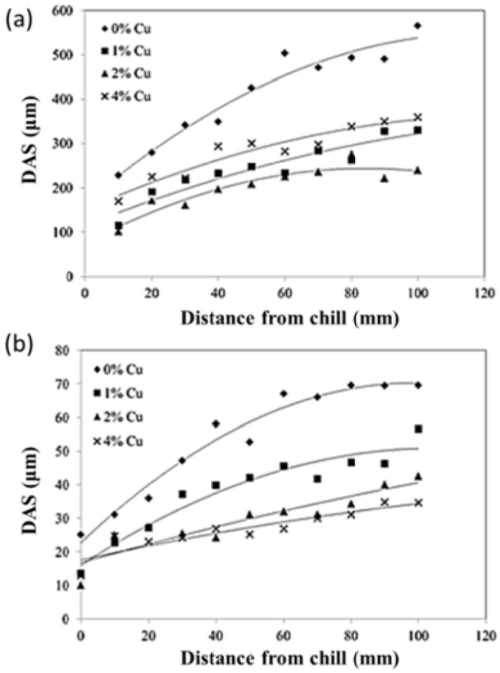

Figure 3 Mean value of dendrite arm spacing as a function of distance from the chill: (a) primary arms; (b) secondary arms

Fig. 4 illustrates the microstructure of Zn-27%Al alloys with different copper content at 20 mm from the chill. According to the Al-Zn phase diagram, solidification of Zn-27%Al alloy begins with precipitation of the Al-rich α phase with a dendritic structure at 493 ^{o}C (area marked with A in Fig. 4a). With decreasing the melt temperature the peritectic reaction (L→α+β) occurs and due to the rapid solidification condition only a thin layer of the β phase forms at the edges of the α phase. The residual liquid becomes enriched with zinc, and the solidification is frequently completed by a divorced eutectic reaction, L→β+η. The eutectic β phase attaches to the peritectic β phase, and η phase distributes in the form of interdendritic layers. The β phase (area marked with B in Fig. 4a) is unstable and decomposes into α and η at the eutectoid temperature.

The microstructure of the ternary Zn-27Al-1Cu alloy in Fig. 4b illustrate that the addition of copper up to 1 wt% made no obvious change in the structure. It is reported that addition of copper in low concentration (<1 wt %) distributes almost uniformly in a macro- and microscopic scale, presenting complete solubility in the matrix. In contrast, addition of copper greater than 1 wt% led to the formation of a new phase in the interdendritic areas. The composition of area marked with F in Fig. 4c confirms the formation of copper-rich phase in the interdendritic regions. Copper has low solubility in zinc. Therefore, when the copper content exceeds 1 wt%, the surplus copper becomes concentrated in the eutectic liquid during the final stage of solidification and as a result a metastable copper-rich ε phase rejects from the liquid in the form of discrete irregular particles.

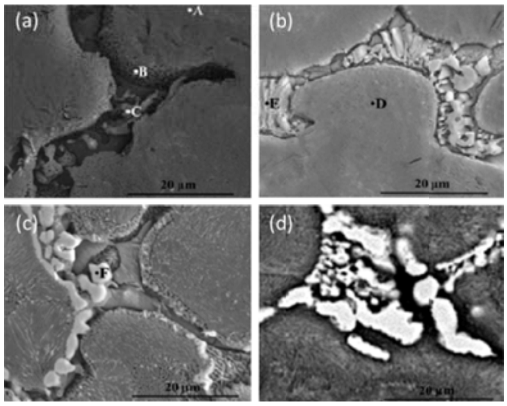

Figure 4 Microstructure of Zn-27%Al alloys with different copper content at 20 mm from the chill: (a) 0; (b) 1; (c) 2; (d) 4 %wt Cu

Fig. 5 shows the effects of cooling rate and Cu content on the percentage of constituents at different positions from the chill. It is clear that with increasing distance from the chill and decreasing DAS the interdendritic phases increase.

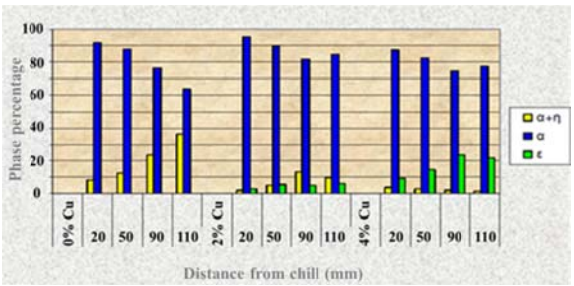

Figure 5 Effects of cooling rate and Cu content on the phase percentage at different positions from the chill

4- Conclusions

End-chill casting established different cooling rates at various distances from the chill and created different microstructures along the cast. With an increase in the distance from the chill, the porosity, DAS and interdendritic phase percentage of the alloy increased.